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To cite this article: Batchuluun Tseveen , Enkhjargal Natsagdorj , Altangerel Balgan , Tsolmon Renchin , Bayanmunkh Norovsuren & Zaya Mart (2020) Impact of logging operations on forest ecosystem in the Khantai mountain region and forest cover mapping, Forest Science and Technology, 16:3, 123-133, DOI: [10.1080/21580103.2020.1796830](https://doi.org/10.1080/21580103.2020.1796830)

To link to this article: <https://doi.org/10.1080/21580103.2020.1796830>



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Published online: 28 Jul 2020.



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Impact of logging operations on forest ecosystem in the Khantai mountain region and forest cover mapping

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ABSTRACT

Forests in Mongolia yield low productivity and are vulnerable to disturbances from drought, fire, pests, and illegal logging. Such forests can quickly lose their ecological balance. Logging activities in these areas are limited in monitoring and controls. This study assesses two different logging operations for their natural regeneration capacity by comparing the composition of the soil, soil organisms, physical and chemical properties, and forest cover change after the completion of logging operations. The logging operations were analyzed in two different regions, the Khartsai and Tariakhtai threshold in Selenge soum, Bulgan province. A skyline logging operation was undertaken on Khartsai threshold in 1983 and a tractor logging operation (clear-cutting) on Tariakhtai threshold in 1987. After the completion of the logging, the forests were naturally regenerated. In 2002, soil samples were collected and soil organisms and physical and chemical properties were examined. Satellite images were also used to evaluate forest cover changes after the end of the logging operations. Significant differences in the naturally regenerated tree species in the skyline logging, tractor logging, and natural forest areas were observed. Average tree ring growth was 0.9 mm in the skyline logging site, 0.6 mm in the tractor logging site, and 1.2 mm in the natural forest. Based on forest cover changes observed in satellite images, the density of naturally regenerated tree species in the natural forest area was higher than that in the skyline logging area. In contrast, the latter recorded a higher density than that in the tractor logging area. Therefore, processing of satellite images of forest cover changes with high-resolution data provides valuable information for the local forest community and helps decision-makers in their further actions.

ARTICLE HISTORY

Received 22 May 2020
Accepted 9 July 2020

KEYWORDS


Forest change; skyline;
tractor; images; Mongolia

Introduction

Mongolia is a landlocked country located in Central Asia and contains transition zones between deserts and boreal taiga of southern Siberia (Tsogtbaatar 2013). These zones reflect a general trend of a dryer and warmer climate in June and September. The average mean temperature in the warmest month is 15–20 °C in the north and 20–25 °C in the south of Mongolia, yet maximum summer air temperatures can reach 35–39 °C in the north and 3–41 °C in the south (Natsagdorj et al. 2018). Forest cover with only 8.1% by closed forest (127,000 km²) of the total land area (1,565,000 km²) of Mongolia (IGG 2018). The closed forest is a dense area of trees mainly located in the north-central parts of Mongolia (Batsukh 2008). Mongolian forests have low productivity and growth, and they are vulnerable to disturbance from drought, fire, illegal/legal

logging, and pests (Sanaa et al. 2018). Therefore, these forests can easily lose their ecological balance due to these disturbances and have a relatively low natural regrowth rate afterwards. Partly owing to the boreal forests being located in the northern hemisphere with a harsh continental climate, which significantly limits the vegetative growth rate and soil moisture content (Tsogtbaatar 2004; Sanaa et al. 2018; Blumroeder et al. 2019). However, the Mongolian forest ecosystem is vulnerable and, therefore, science-based advanced technology should be applied to use it in a sustainable way, e.g. through science-based satellite image processing and analyzing of the forest ecosystems.

Over the past 20 years, the forest area has been decreased by 1.2 million hectares due to forest fire, insect expansion, and illegal logging in Mongolia (MET 2017b). Deforestation and forest degradation are

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influenced by following factors: fire, pests, grazing, soil erosion, and logging (Sanaa et al. 2018). The National Statistics Office (NSO) estimates average timber consumption, including legal and illegal production, around 5.51 million cubic meters, about five times the sustainable annual harvest volume. However, the Mongolian government has restricted annual legal harvest limits to 617,200 cubic meters which as average national predicted consumption (Jeffrey 2011). Many logging practices in Mongolia are unsustainable and consequently lead to long-term forest degradation. Logging companies do not follow best practices for sustainable forest management, and reduced impact logging is not practiced (FAO 2014). Therefore, one reason for forest degradation is the wrong logging system applied in forests in Mongolia.

Remote sensing (RS) and Geographic Information System (GIS) provide excellent tools for monitoring the suitability of logging operations and examining the forest cover change in Mongolia, moreover to costing less and requiring less fieldwork. Due to Mongolia's vast territory, through the application of remote sensing techniques and satellite images, we believe that a detailed accuracy assessment of the current state of forest cover can be more quickly and accurately estimated. Therefore, the country requires the processing of satellite images and monitoring of forest changes, especially in its logging areas. To reduce deforestation due to logging operations, forest mapping, and monitoring of their evolution are essential. Forest cover change mapping is crucial for the local forest community to control forests. Several forest monitoring projects have used satellite data including the Moderate Resolution Imaging Spectroradiometer (MODIS) (Hilker et al. 2014; Eckert et al. 2015), Landsat TM/ETM/OLI (thematic mapper/enhanced thematic mapper/operational land imager) (Chen et al. 2003; Gevaert and García-Haro 2015; Félicité Temgoua et al. 2018), and Sentinel-2 MSI (multispectral instrument) (Wang and Atkinson 2018), which includes tree canopy mapping, vegetation cover monitoring, burned areas, and logging monitoring. High spatial resolution Landsat data allow for more accurate change area measurements to be performed. However, owing to the cost and infrequent repeat coverage, the use of Landsat data for mapping on an annual basis is problematic. Therefore, sampling approaches for forest cover change estimation have been applied in many land cover change studies (Chen et al. 2003; Bayarsaikhan et al. 2009; Lamchin et al. 2016). In high-resolution satellite data acquisition, forest cover changes influenced by logging practices, fire, and pests can be identified to help manage and transform data into actionable knowledge of changes in forest ecosystems that can be used for decision making and policy planning purposes.

In the present study, we aimed to answer the following question: how do logging operations reflect on forest ecosystems in Mongolia? According to this question, the answer will clarify the following objectives included, (1) to estimate the tree growth and how they are effected by logging operations; (2) compare the

difference of the soil physical and chemical properties of different logging areas, and (3) estimate changes in forest cover using Landsat images between 1989 and 2019. The main goal of the present study was to assess different logging operations for their natural regeneration capacity by comparing the soil physical and chemical properties and forest cover change after the completion of different logging operations. We compared skyline logging, tractor logging (clear-cutting), and natural forested areas. It will provide useful information for sustainable forest management, especially for logging arrangement in local communities and decision-makers.

Material and methods

Study site

Mongolia's forest resources span over 1.39 billion cubic meters, with an average annual growth of 11.6 million cubic meters, of which 23.7% are in the utilization zone forests and 76.3% in the protected zone forests (MET 2017a). Forests are divided into two major types: boreal forests in the north and dryland woodland ecosystem in the southern arid regions. The boreal forests account for 14.2 million ha (87%) and are dominated by larch and birch in northern Mongolia and 2.0 million ha of saxaul forests (13%) in southern Mongolia (Sanaa et al. 2018). The boreal forest comprises deciduous and coniferous forests growing in the forest-steppe, boreal forest, and mountain zones. The following six main conifer species dominate in the boreal forest: larch (*Larix sibirica*), birch (*Betula platyphylla*), Siberian pine (*Pinus sibirica*), Scots pine (*Pinus sylvestris*), aspen (*Populus tremula*), and spruce (*Picea obovata*) with the majority of the forests dominated by larch (FAO 2014). Dryland woodland are dominated by saxaul (*Haloxylon ammodendron*) trees in the desert zone which is located in the southern part of Mongolia. A saxaul forest is a unique brushwood to obtain the environment of plants, the animal kingdom, microclimate condition and soil. Saxaul forest vegetation consists mainly of a dry land plant as it has many characteristics of biological and ecological adoption to the dry climate (Suvdantsetseg et al. 2008).

The study area is located in the northern part of Mongolia (49°39'–49° 42' N and 103°51'–103°56' E) in Selenge soum, Bulgan province (Figure 1) with an average elevation of 1406 meters. The study area covered 3206.63 ha in Khantai mountain, Bulgan province, as shown in Figure 1. Three observation sites were selected in different logging areas: Khartsai (shown A), Tariakhtai (shown as B), and the natural forest of Khartsai threshold (shown as C) (Figure 1).

The study area had low average temperatures, ranging from 15 to 20°C. The annual total precipitation was approximately 250–300 mm in the taiga and forest-steppe regions, and 150–250 mm in the steppe regions (Batima et al. 2005). The Selenge soum contained 395,247 ha of forested area and is characterized by alpine forests, gradually blending in the arid steppe plains of

the central Mongolian highland. Based on the Holdridge life zones system of bioclimatic classification, Bulgan is situated in the boreal dry scrub biome (larch, birch, and shrub) where larch makes up 86.12% and birch 13.88% (FAO 2014). The area was divided based on logging operations from the available logging history of the reserve (Table 1). Figure 1 shows the location of the logged area and un-logged area, including the skyline logged (A), tractor logged (B) and non-logged/natural forest (C) areas. The study area is characterized by slopes between 10 and 25% e.g. slope was 23.5% in the skyline logged (1,366 m); 15.05% was in the tractor logged (1,436 m) and 12% was in natural forest (1,417 m) slope (Table 1).

Logging operations

From 1987 to 2000, timber were harvested annually, yielding 1.5–2 million cubic meters from the forest utilization areas from the study area and the average distance of timber transportation was 65 km (Batchuluun 2010).

Skyline logging

There exist many different rigging configurations, including high lead, standing, running, and live.

The high lead system is not a skyline system. The standing, running, and live systems are skyline systems; however, they all utilize a skyline cable (Baumgras and Ledoux 1995; USDA 2018). Live skyline was carried out on the study area in 1987 by a ML-43 machine (location A in Figure 1). A live skyline is a system in which the skyline itself is raised and lowered to position the carriage. This system is operated with non-slack-pulling carriages, and it requires a two-drum yarder when operating uphill. A third drum for a haul back is required for downhill yarding and slopes lower than 20%. A 100 × 50 m trench was constructed at the survey site, and a 5 m wide whitewash road was constructed in the center of the field. The rope device (ML-43) was whitewashed with a semicircle at the end. On steep terrain, this system uses a steel cable to carry whole trees of logs to a landing after trees are felled with chainsaws (AOL 2011).

Tractor logging

Major timber industry towns were established in many forested areas, and entire communities began to depend on a single forestry sector. The environmental impact was enormous; however, because these enterprises used clear-cutting forestry techniques of the

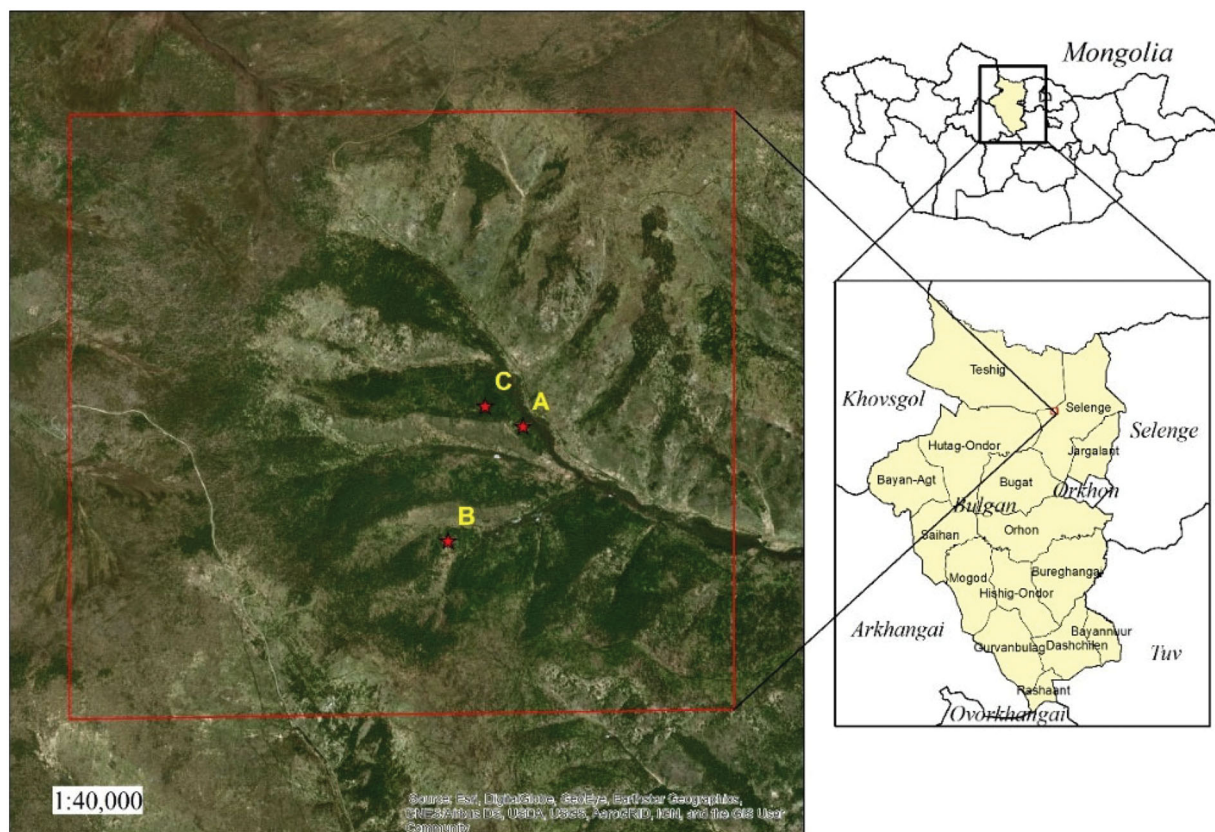


Figure 1. Location of the study area with the natural color composite from satellite images and location of the fields (A, B, and C); A is in the Khartsai threshold, B is in the Tariakhtai threshold, and C is the natural forest in Selenge soum, Bulgan province, Mongolia. The study site area: 3206.63 ha.

Table 1. Categories of logging operation areas in the forest.

Codes	Name	Types of logged operation	Longitude (E)	Latitude (N)	Altitude, (m)	Slope, %
A	Khartsai	Skyline logging	103° 53' 24.71"	49° 41' 14.22"	1,366	23.5
B	Tariakhtai	Tractor logging	103° 53' 29.41"	49° 39' 39.84"	1,436	15.05
C	Natural forest	Non-logging	103° 53' 36.28"	49° 41' 8.12"	1,417	12.0

Soviet Union, they were inappropriate for Mongolia's limited forest resources. One method of transporting logs from the forest is by dragging them with a tractor (Hensley 1998). Tractor logging was undertaken in 1983 by a TT-4 chain tractor (Location B in Figure 1). In the study area, an excavation area (250×150 m) was established, trees were cut flat, and tracks were whitewashed with a crawler tractor; and trees were cut down chaotically. Hand-operated chainsaws are used to cut, delimb and buck trees into logs at the stumps. Tractors drag the trees to a landing, where they are loaded onto trucks (AOL 2011).

Figure 2(a) shows study site (A) which was at the skyline logging site with strips 100×50 m in 1987 by ML-43 technique. This photograph was taken in September 2004, and Figure 2(b) shows the same site in June 2018. Figure 3(a) shows study site (B), which utilized clear-cutting with crawler tractor (TT-4) in 1983. This photograph was taken in September 2004, and Figure 3(b) shows the same site in June 2018.

Data collection and analysis

The present study measured changes in soil chemical and physical properties, tree growth, and forest cover changes after the logging operations in different areas using Landsat TM/OLI images between 1989 and 2019. The main goal of the present study was to assess different logging operations for their natural regeneration

capacity by comparing soil physical and chemical properties and forest cover change after the completion of the different logging operations. During this research, the following three datasets were used: soil measurements, tree growth from field surveys, and satellite data (Tables 2 and 3).

Ground truth data and analysis

The soil samples were collected and measured using physical (soil texture) and chemical (soil organism) properties from the different logging areas. Each logging area had 50 soil samples were collected. The instruments that were used included Global Position System (GPS), a compass, diameter tapes, soil sieves (2–10 mm), sample containers, data collection sheets, and cutlasses (Table 2 and Figure 4). Furthermore, to estimate forest regeneration, we collected data from 50 sites measuring 10×10 meters each and where we counted young trees as well as growth of trees of each logged area and natural forest. A sample to determine the transverse growth of the tree was taken with a growth drill (Presler). The samples were measured mechanically with ordinary magnifying glass and TVC-10 stereo microscopes with an accuracy of 0.01, 0.05, and 0.1 mm. Samples were compared under a microscope and growth was measured using a line with a normal scale.

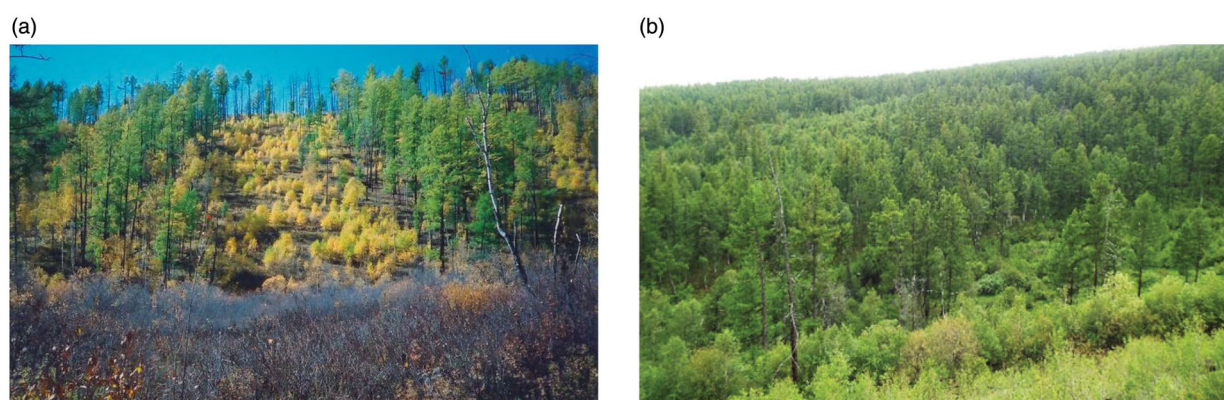


Figure 2. Skyline logging area (A) in Khartsai threshold (a) 2004, (b) 2018.

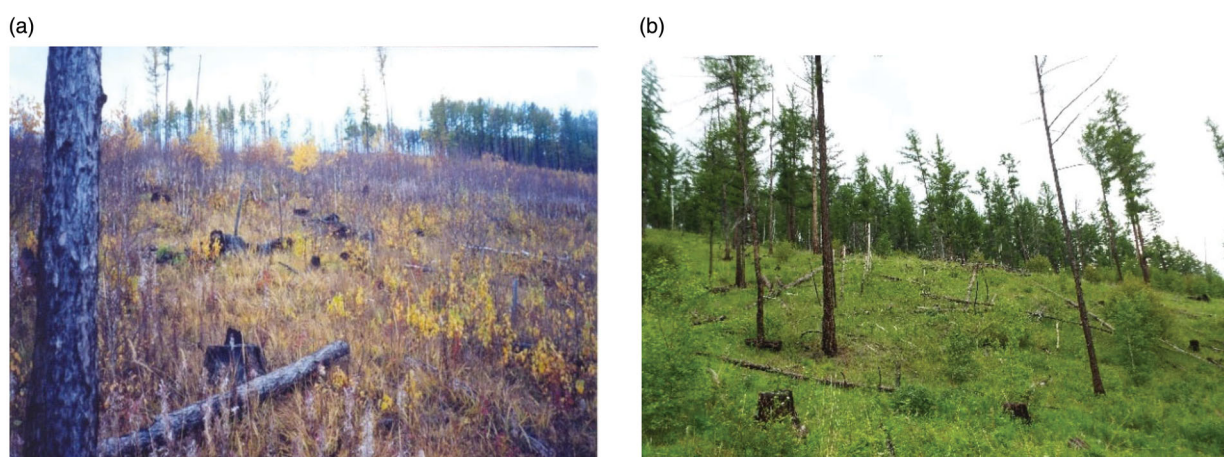


Figure 3. Tractor logging (clear-cutting) area in Tariakhtai threshold: (a) 2004, (b) 2018.

Table 2. Data descriptions.

No	Data type	Descriptions	Acquired date
1	A transverse section of the trunk of a tree	A random sample were collected from each site using measuring the trunk (skyline, tractor and natural forest). Figure 2(a) shows how the samples were collected (taking core samples).	September, 2002
2	Mechanic composition of the soil in logging area	In the soil samples, soil particles, hygroscopic moisture and mechanical component were measured in each study site.	June, 2004
3	Soil temperature	The soil temperature was measured in each study site.	June and September, 2017
4	Soil chemical parameters	Soil chemical parameters were measured in the soil laboratory. Soil pH and Ca was described from the samples in each logging area.	June, 2004
5	Soil microorganisms (bacteria, actinomycetales, mold)	Soil microorganisms were estimated from the samples in the Microbiology laboratory at the National University of Mongolia.	June, 2004
6	Field trip of land cover	Collected samples on different logging areas	June, 2018

Table 3. Acquired satellite remote sensing data.

Satellite	Acquisition Date	Resolution	Level	Spectral bands used
Landsat TM 4,5	1989, 1995, 1999, 2004, 2009	30 m	–	Blue, Green, Red, NIR
Landsat OLI 8	2014, 2019	30 m	–	Blue, Green, Red, NIR

Source. National Aeronautics and Space Administration (NASA), USA

(a)



(b)



Figure 4. The ground truth measurements in the Khartsai threshold (A site) (a) field measurement (taking core samples from *Larix Sibirica*) in September 2002, (b) field measurement in June 2018.

Bacteria represent another important, though less explored part of the microbial community in forest soils (Lladó et al. 2017). Soil bacteria were measured from the soil samples to obtain the number of bacteria per gram of soil in the microbiological laboratory (Table 2). General bacterial counts and antagonistic microorganisms were performed: MPB, MPA medium and the actinomycete-defined environment were examined: CAA (coral-associated actinomycetes) environment (ADMNEA 2000).

Satellite data and analysis

The Landsat Thematic Mapper (TM) sensor was used on Landsat 4, while Landsat 5 provided images consisted of six spectral bands with a spatial resolution of 30 m for Bands 1 to 5 and 7, and one thermal band (Band 6). Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor images consist of nine spectral bands with a spatial resolution of 30 m for Bands 1 to 7 and 9. The ultra-blue Band 1 is useful for coastal and aerosol studies. Band 9 is useful for cirrus cloud detection. The resolution for Band 8 (panchromatic) is 15 m. Thermal bands 10 and 11 are useful in

providing more accurate surface temperatures and are collected at 100 m resolution. The approximate scene size was 170 km north-south by 183 km east-west for Landsat TM and OLI (Table 3).

Landsat TM/OLI images (1989–2019, path 133, row 26) was downloaded from the USGS Earth Resource Observation and Science Center website and utilized in this research. Landsat is free and downloadable (<http://glovis.usgs.gov/>). Landsat TM/OLI was used to evaluate forest cover change using the normalized difference vegetation index (NDVI).

NDVI is the most widely used index for monitoring and land cover changes. NDVI is calculated from red (RED) and NIR bands from Landsat images (Los et al., 1994):

$$NDVI = (NIR - RED) / (NIR + RED), \quad (1)$$

where RED is the visible red reflectance and NIR is the near-infrared reflectance. The wavelength of NIR band is 750 – 1300 nm and the RED band is 600 – 700 nm.

The forest cover mapping was processed from Landsat TM/OLI images from 1989 to 2019. Figure 5 illustrates this for the boreal forest in the study site of

the Khartsai mountain, showing band combination with Band 543 of Landsat TM and Band 654 of Landsat OLI. These images were processed using ENVI 4.7 and ArcGIS 10.3 software to extract the desired information. Forest fires occurred in this study area in 1990, 1996, and 1998 (NEMA 2004).

The general procedure undertaken in the present study is shown in Figure 6, which shows the three datasets that were applied.

Results and discussions

In the present study, we examined the implications of the different logging methods on the growth of natural

vegetation in the forest cover and logging areas, and obtained the following results.

Tree growth and soil recovery

The results obtained from the estimation of the average growth rings per site in the different logging areas are summarized in Table 5 and Figure 7. After the logging operations occurred, the results obtained for the core samples of the average tree growth from the skyline logging site was 0.9 mm, tractor logging site was 0.6 mm, and the natural forest site was 1.2 mm. Standard deviation of tree growth from samples in the skyline logging was 1.09, tractor logging was 0.6 and natural forest was 1.5.

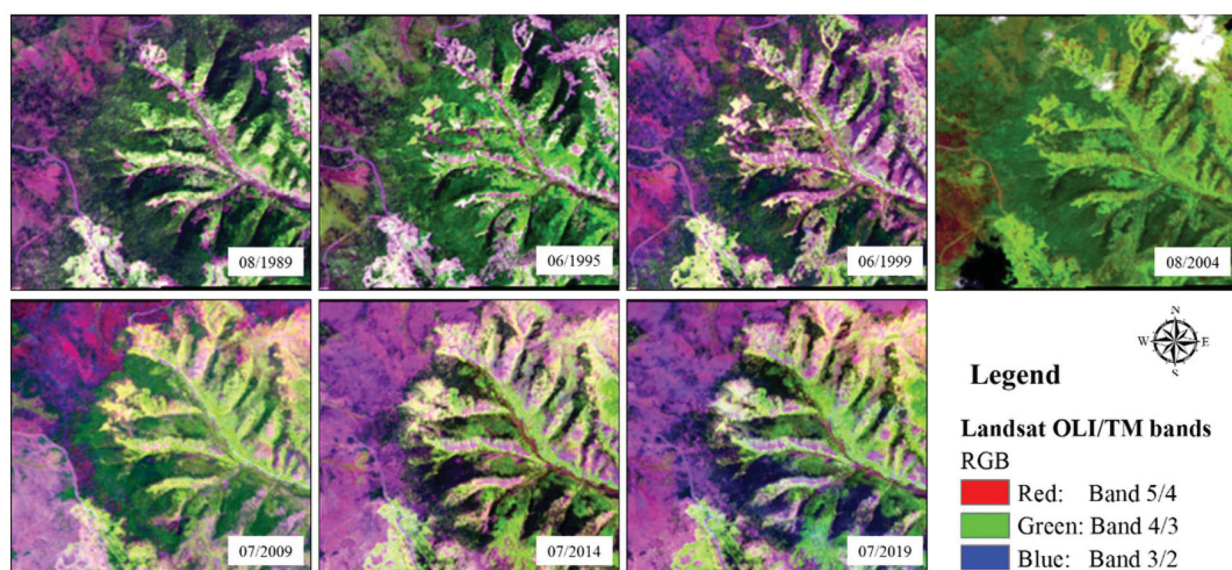


Figure 5. Forest cover changes areas in Landsat TM/OLI data 30 m resolution (band combination 543 bands).

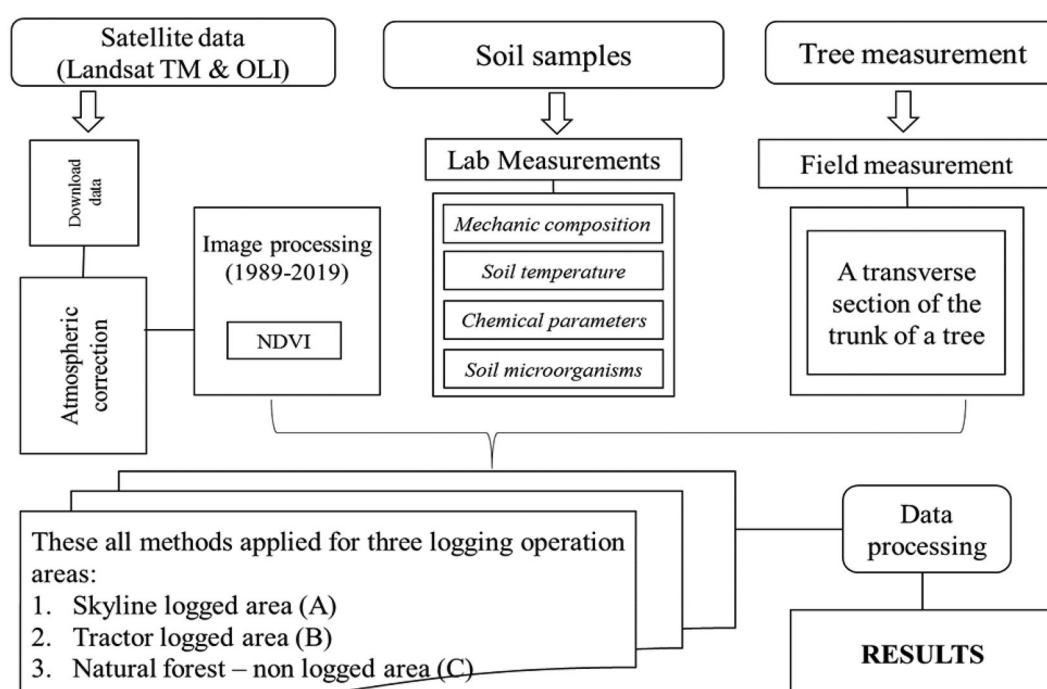


Figure 6. Flowchart of the present study.

Annual rings were measured and averaged for each of the 50 sampled trees. This shows that the forests in the study areas are divided into two age groups. There are trees over 200 years old and young forests 29 – 61 years old. During the field trip, a total of 1,291 years of rings were measured. The correlation between the series of samples is 0.75 which is a high correlation (Table 4).

Soil texture

The vegetation condition of the forest is determined by the total concentration of soil humus, soil solubility reaction, the thickness of soil layers and gravel, and their physical and biological properties, as well as water temperature regimes (Ogorodnikov 1981). Therefore, it is necessary to increase soil productivity of the logging area. The clay and light clay loam soils dominated the composition of the particles and their composition contained more sand and coarse dust fractions than the others. In the upper part of the soil, coarse dust (0.05 – 0.01 mm in diameter) had a high

Table 4. Impacts of logging operations for average growth ring (mm) core samples from the *Larix sibirica*.

Samples area	Average growth ring (mm)	Soil damage
Skyline logging (A)	0.6–1.1	Low
Tractor logging (B)	0.4–0.7	High
Natural forest (C)	0.7–1.5	None

fracture density, which is a characteristic of the taiga soil under permafrost conditions (Ogorodnikov 1981). The results of the soil sample measurements of the mechanic composition are shown in Table 5. From the result of soil texture, the mechanical composition of the soil in the study areas is all moderately clay. The difference in soil texture (0.05–0.01 mm in diameter) fraction was 21.4% in area B which was tractor logged, 28.5% in area A which was skyline logged, and 22.3% in area C which was natural forest.

Soil temperature

Soil temperature is essential for forest growth and development. The seeds of pine and spruce are grown at 3 – 37 °C and the roots of the woody plants can survive at a temperature not higher than 5 – 6 °C (Pobedinsky 1979). The soil temperatures of the samples were measured in June and September 2017 (Tables 6 and 7).

Tables 6 and 7 show that the average soil temperature in the area (B) cleared by a tractor is 1.7 times higher at a depth of 5 cm, 1.8 times higher at 10 cm, 1.7 times higher at 20 cm, and 1.8 times higher at 30 cm. Compared to the original forest, the average soil temperature of the cleared area (A) by skyline is 1.5 times higher at 5 cm depth, 1.6 times higher at 10 cm, 1.6 times higher at 20 cm, and 1.8 times higher at 30 cm. This means that the soil temperature in the

Table 5. Mechanic composition of the soil of logging areas (A, B, C).

Samples area	Soil particle size, mm (%)							Hygroscopic moisture, %	Mechanical component
	1–0.25	0.25–0.05	0.05–0.01	0.01–0.005	0.005–0.001	<0.001	<0.01		
Skyline logging (A)	6.4	30.7	28.5	8.2	10.3	15.1	34.0	3.1	Mid clay
Tractor logging (B)	7.1	40.9	21.4	9.4	6.7	13.7	30.2	2.3	Mid clay
Natural forest (C)	5.4	28.1	22.3	13.4	11.2	15.4	39.8	2.7	Mid clay

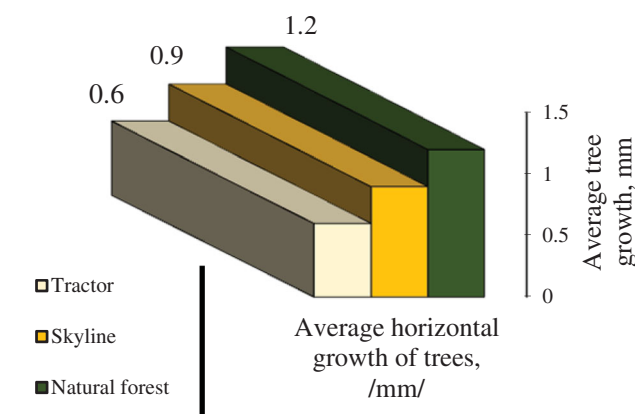


Figure 7. Average growth rings (mm) of the radial growth of trees/mm.

Table 6. Soil temperature of the logging by skyline (A), (2017).

Months	Soil surface depth, cm			
	5	10	20	30
6	12.4/7.4	11.4/6.8	10.2/5.8	11.6/5.6
9	8.5/6.2	9.1/5.6	8.9/5.4	8.3/5.1
Mean value	10.4/6.8	10.2/6.2	9.5/5.6	9.9/5.3

Note. To be in numerator soil temperature logging area and to be in quota soil of nature forest

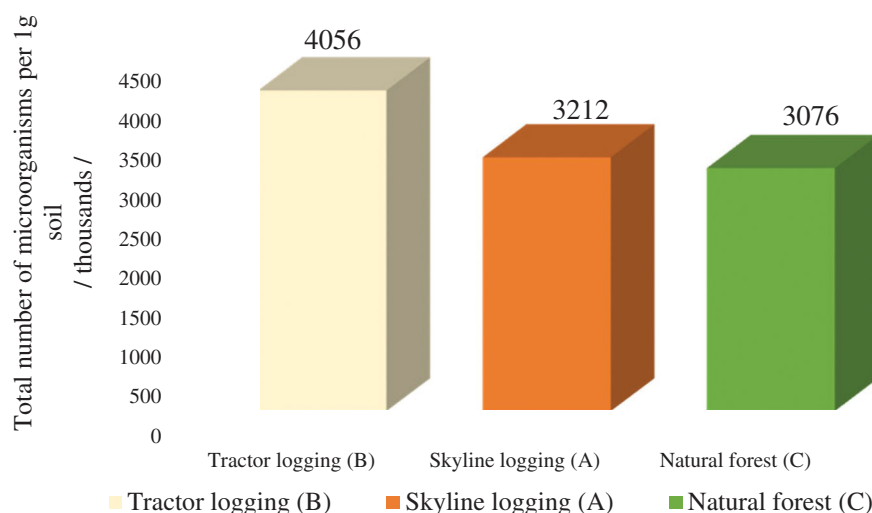
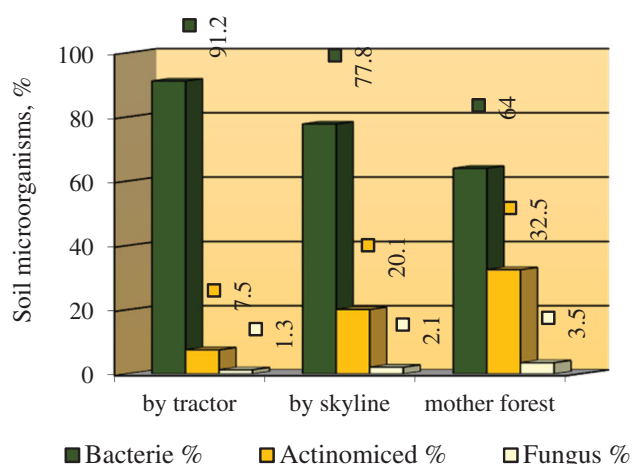
Table 7. Soil temperature of the clear-cutting area, logging by tractor (B), (2017).

Months	Soil surface depth, cm			
	5	10	20	30
6	18.4/8.6	16.8/7.4	15.3/7.1	15.6/6.8
9	10.5/8.2	10.8/7.6	10.6/7.4	10.3/7.1
Mean value	14.4/8.4	13.8/7.5	12.9/7.2	12.9/6.9

Note. To be in numerator soil temperature logging area and to be in quota soil of nature forest

Table 8. The ratio of soil microorganisms.

Soil sample	Total number of microorganisms per 1 g /thousand/	From that (%)		
		Bacteria	Actinomycetales	Mold
Skyline logging (A)	3212	77.8	20.1	2.1
Tractor logging (B)	4056	91.2	7.5	1.3
Natural forest (C)	3076	64	32.5	3.5

**Figure 8.** Number of microorganisms per 1 gram of soil (thousands).**Figure 9.** Ratio of soil organisms by percent in sampling areas.

area cleared by a tracked tractor is relatively high. For example, the soil temperature at a depth of 5 cm is 14.40 °C, which is 1.38 times higher than the temperature of the skyline logged area.

Soil microbiological parameters

The distribution, quantity, and species composition of microorganisms reflect biological processes of the soil (Ejov 1981; Galt 2009). The most common types of bacteria are *Bacillus*, *Azotobacter*, *Pseudomonas*, *Clostridium*, *Staphylococcus actinomyces*, *Micromonospora*, *Streptomyces* sp., *Mucor*, *Aspergillus*, and *Penicillium*-type fungus (Krasilnikov 1958). In investigating the spread of soil microorganisms, bacteria were injected into meat peptone agar, actinomycetes in starch-ammonia agar and molds in *chapek* feeding environments. The distribution of microflora in 1-g of soil is shown in Table 8 and Figure 8.

All samples in the soil bacteria were higher in the soil (64 – 91.2%) than in other groups such as mold and actinomycetales; however, as the soil became damaged, the bacteria increased, and the number of molds and actinomycin decreased (Table 8). Also, the Table 8 shows that the number of microorganisms in the soils samples is different, and the number of bacteria in 1 g of the forest soil of cleared by a crawler tractor was higher than in the skyline logged area and natural forest soil. As the soil was damaged, the acidity of the environment changed, and its layers became dry as moisture was lost, and the number of molds decreased. According to the analysis results, 1 g of the mother forest soil contained 64% bacteria, 32% of actinomycin, and 3.5% fungi (Figure 9).

Hygroscopic moisture was 2.3% in the tractor logging site, 3.1% in the skyline logging site, and 2.7 in the natural forest site. Soil pH was 5.83 in the skyline, 6.28 in the tractor logging and 7.24 in the natural forest sites. Soil humus was 4.11 in the skyline, 1.72 in the tractor logging, and 10.54 in the natural forest sites (Figure 10). Therefore, the soil changed differently depending on which logging operations were undertaken.

As soil erosion increases, the number of actinomycetes and fungi, which play an essential role in soil fertility by decomposing organic compounds that are not broken down by other microorganisms through a powerful enzyme system, is declining.

Forest cover change in different logging areas

The most common form of vegetation index is the NDVI, which was estimated from Landsat images of the study area from 1989 to 2019. Previous studies have

undertaken NDVI classification for land cover and land-use change (Erdenetuya 2009; Gandhi et al. 2015; Wei et al. 2018). NDVI mapping identified five classes, namely water, bare land, grassland, sparse vegetation, and dense vegetation/forested area based on reviews. NDVI classified the following classes: water (-1 to 0), bare land (0 – 0.2), grassland (0.2 – 0.4), sparse vegetation (0.4 – 0.5), and dense vegetation/forested area (0.5 – 1.0) (Figure 11). The points of logging operations were overlaid on NDVI. The results of each location are shown in Figure 12.

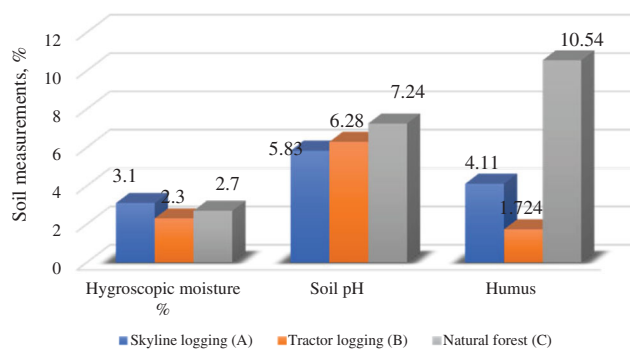


Figure 10. Results of soil measurements.

(0.5 – 1.0) (Figure 11). The points of logging operations were overlaid on NDVI. The results of each location are shown in Figure 12.

Over the 20 years (1989 – 2019), vegetation decreased by 44% in the study area. In August 1989, NDVI was 0.55 in the skyline site, 0.57 in the tractor logging site, and 0.56 in the natural forest site. In June 1995, NDVI was 0.62 in the skyline site, 0.59 in the tractor logging site, and 0.57 in the natural forest site. In June 1999, NDVI was 0.62 in the skyline site, 0.67 in the tractor logging site, and 0.63 in the natural forest site. In August 2004, NDVI was 0.59 in the skyline site, 0.62 in the tractor logging site, and 0.59 in the natural forest site. In July 2009, NDVI was 0.60 in the skyline site, 0.57 in the tractor logging site, and 0.63 in the natural forest site. In July 2014, NDVI was 0.41 in the skyline site, 0.49 in the tractor logging site, and 0.44 in the natural forest area. In July 2019, NDVI was 0.41 in the skyline logging site, 0.49 in the tractor logging site, and 0.42 in the natural forest (Figure 12).

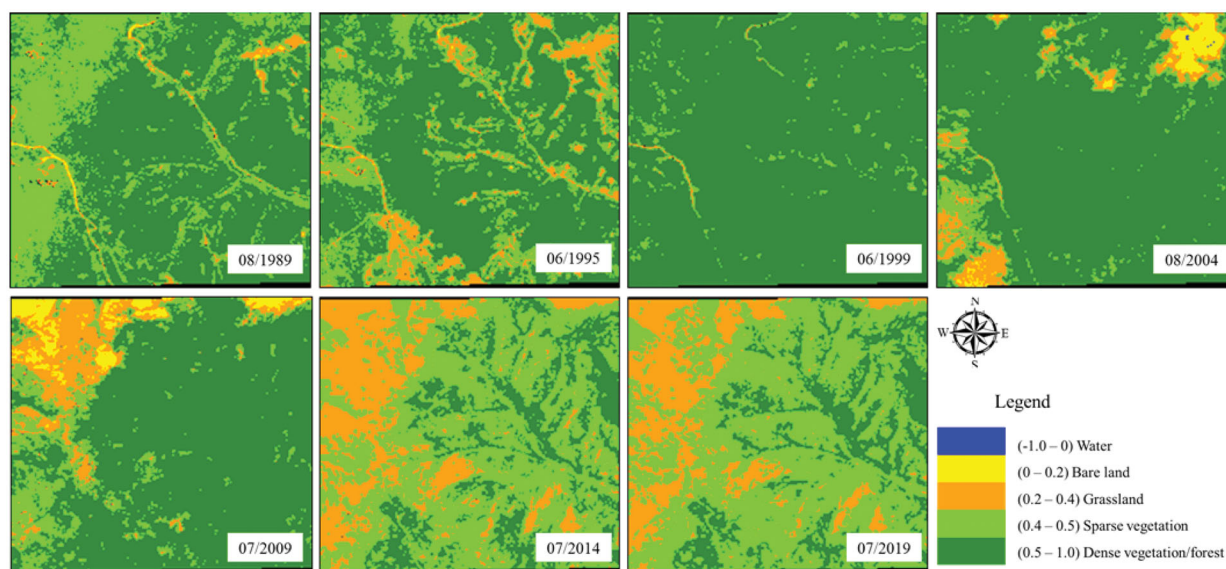


Figure 11. NDVI classification map: blue color is water, yellow is bare land, orange is grasslands, green is sparse vegetation and sea green is dense vegetation and forested area.

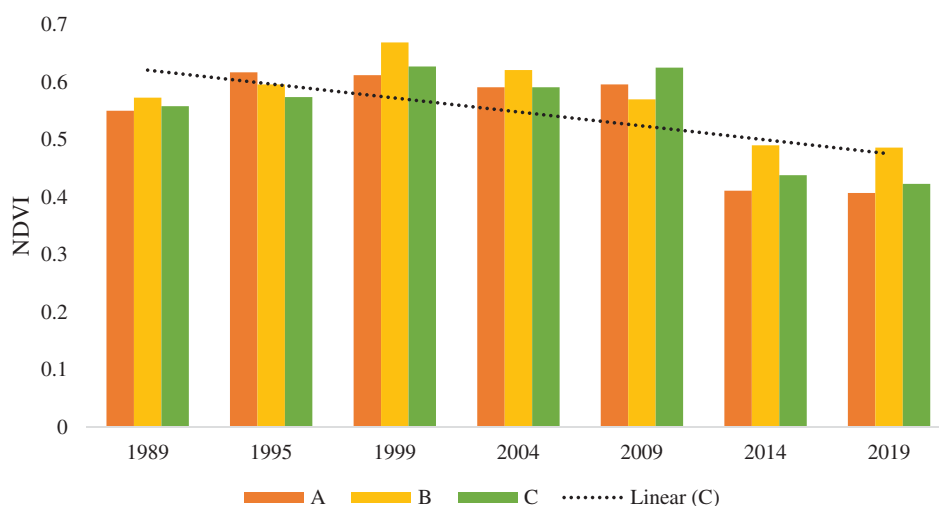


Figure 12. NDVI at logging areas (A) skyline logging, (B) tractor logging and (C) natural forest.

Conclusions

Although not as conspicuous as deforestation, the impact of logging operations on the environment can be considerable. Forest fire, logging, and grazing activities are the major factors changing plant community composition and succession in Mongolia (Tsogtbaatar 2004). Two different logging operations were measured in the study areas. Soil parameters, tree measurements, and land cover changes were analyzed for the logging operation sites, which included skyline and tractor logging (clear-cutting) and natural forest.

The estimated tree ring growth was measured as 0.9 mm in the skyline logged site, 0.6 mm in the tractor logged site, and 1.2 mm in the natural forest site. According to the results of the analysis, 1 gram of natural forest soil contained 64% bacteria, 32% actinomycin, and 3.5% fungi. The soil was damaged due to tractor logging (clear-cutting) because the acidity of the environment changed, and the soil layers were dry and contained a decreased number of molds. However, from the NDVI results, there was no significant difference between the skyline and tractor logged sites.

The present study clarified which logging operation was suitable for the Mongolian forest ecosystem. The tractor logging (clear-cutting) operation is not applicable in the mountainous Mongolian forest because it leads to the successional change of coniferous forest with deciduous forests and the replacement of forest ecosystems. Therefore, silvicultural application and logging activities in Mongolia require special logging operations and systems that will not have a destructive effect on the protective function of the forest ecosystem and allow for a natural regeneration of forests. Satellite image processing of forest cover change with high-resolution data provides valuable information for the local forest community and future actions of decision-makers.

Acknowledgements

We acknowledge the two anonymous reviewers for their valuable comments, which significantly improved our paper. The authors wish to express their sincere thanks to the Asian Research Center (ARC), Mongolia based on Korea Foundation for Advanced Studies Research Grant (P2017-2489) for their financial supports.

Disclosure statement

No potential conflict of interest was reported by the author(s).

References

ADMNEA. 2000. "Technical manual for soil and vegetation monitoring in East Asia."

AOL. 2011. "Sustainable forestry is vital to oregonians way of life and rural economy."

Batchuluun T. 2010. The operation of the mongolian forest resource and research of logging technology. Mongolia: National University of Mongolia.

Batima P, Gombluudev P, Natsagdorj L, Erdenetsetseg B. 2005. "Observed climate change in mongolia." *Ulaanbaatar*; [accessed 2020 July 16]. www.aiaccproject.org.

Batsukh N. 2008. "Mongolian Forest Ecosystem."

Baumgras JE, Ledoux CB. 1995. Economies of hardwood silviculture using skyline and conventional logging." In *Hardwood Symposium Proceedings*, p. 5–17. North Carolina.

Bayarsaikhan U, Boldgiv B, Kim KR, Park KA, Lee D. 2009. Change Detection and Classification of Land Cover at Hustai National Park in Mongolia. *Int J Appl Earth Obs Geoinf*. 11(4):273–280.

Blumroeder JS, Burova N, Winter S, Goroncy A, Hobson PR, Shegolev A, Dobrynin D, Amosova I, Ilina O, Parinova T, et al. 2019. Ecological effects of clearcutting practices in a boreal forest (Arkhangelsk Region, Russian Federation) both with and without FSC certification. *Ecol Indic*. 106:105461.

Chen S, Xiao X, Liu J, Zhuang D. 2003. Observation of land use/cover change of the xilin river basin, inner mongolia using multitemporal landsat images. In: Pan X, Gao W, Glantz MH, Honda Y, editors. *Ecosystems dynamics, ecosystem-society interactions, and remote sensing applications for semi-arid and arid land*. Vol 4890. Bellingham: SPIE; p. 674.

Eckert S, Hüslér F, Liniger H, Hodel E. 2015. Trend analysis of MODIS NDVI time series for detecting land degradation and regeneration in Mongolia. *J Arid Environ*. 113:16–28.

Ejov GI. 1981. *Руководство к Практическим Занятиям По Сельскохозяйственной Микробиологии*. Moscow.

Erdenetuya M. 2009. Land cover change and pasture estimation of Mongolia from space – *Geospatial World*." 2009. [accessed 2020 Feb 16]. <https://www.geospatialworld.net/article/land-cover-change-and-pasture-estimation-of-mongolia-from-space/>.

FAO. 2014. "Mongolia – Global Forest Resources Assessment 2015." [accessed 2020 Feb 16]. <http://www.fao.org/3/a-au190e.pdf>.

Temgoua LF, Momo Solefack MC, Nguimdo Voufo V, Tagne Belibi C, Tanougong A. 2018. Spatial and temporal dynamic of land-cover/land-use and carbon stocks in eastern cameroon: a case study of the teaching and research forest of the University of Dschang. *Forest Sci Techno*. 14(4):181–191.

Galt L. 2009. *Microbiology*. Ulaanbaatar: Institute of Microbiology.

Gandhi GM, Parthiban S, Thummalu N, Christy A. 2015. Ndpi: vegetation change detection using remote sensing and gis – a case study of Vellore District. *Procedia Comput Sci*. 57: 1199–1210.

Gevaert CM, García-Haro FJ. 2015. A comparison of STARFM and an unmixing-based algorithm for landsat and MODIS data fusion. *Remote Sens Environ*. 156:34–44.

Hensley EC, Andrew. 1998. *Forest operations textbook*. 1998. [accessed 2020 Feb 16]. https://www.fs.fed.us/t-d/programs/forest_mgmt/projects/textbook/systems/farmtractor.html.

Hilker T, Natsagdorj E, Waring RH, Lyapustin A, Wang Y. 2014. Satellite observed widespread decline in mongolian grasslands largely due to overgrazing. *Glob Change Biol*. 20(2):418–428.

IGG. 2018. "Монгол Орны Ойн Тархалт – Өгөгдлийн Бурдлууд – IGG Knowledge Portal." 2018. [accessed 2020 Feb 16]. <http://portal.igg.ac.mn/dataset/oin-zurag>.

Jeffrey R. 2011. *Mongolia's environmental security*. Chinese

Krasilnikov NA. 1958. *Микроорганизмы Почвы и Высшие Растения*. Изд-во. Советская наука, Moscow. стр. 117–119.

Lamchin M, Lee J-Y, Lee W-K, Lee EY, Kim M, Lim C-H, Choi HA, Kim SR. 2016. Assessment of land cover change and desertification using remote sensing technology in a local region of Mongolia. *Adv Space Res*. 57(1):64–77.

Lladó S, López-Mondéjar R, Baldrian P. 2017. Forest soil bacteria: diversity, involvement in ecosystem processes, and response to global change. *Microbiol Mol Biol Rev*. 81(2): e00063–16.

Los SO, Justice CO, Tucker CJ. 1994. A global 1° by 1° NDVI data set for climate studies derived from the GIMMS continental NDVI data. *Int J Remote Sens*. 15(17):3493–3518.

MET. 2017a. *Environmental state report of Mongolia*. Ulaanbaatar.

- MET. 2017b. "Ministry of Environment and Tourism – Welcome." 2017. [accessed 2020 Feb 16]. <http://www.met.gov.na/>.
- Natsagdorj E, Renchin T, De Maeyer P, Dari C, Tseveen B. 2018. Long-term soil moisture content estimation using satellite and climate data in agricultural area of Mongolia. *Geocarto International*. 34(7):722–734.
- NEMA. 2004. Database of the national emergency management agency. 2004. [accessed 2020 Feb 16]. <http://map.nema.gov.mn/>.
- Ogorodnikov AV. 1981. Почвы Горных Лесов Монгольской Народной Республики, Наука. Сибирское отделение, Новосибирск. 142с.
- Pobedinsky AV. 1979. Водоохранная и Почвозащитная Роль Лесов. Moscow., Лесн. Пром-Ность. 174с.
- Sanaa E, Nyamsuren D, Purevjav Z, Battuvshin K, Altangadas J, Khaltar M. 2018. "Mongolia's Forest Reference Level Submission to the United Nations Framework Convention on Climate Change. UN-REDD Mongolia National Programme, Ministry of Environment and Tourism." [accessed 2020 Feb 16]. www.reddplus.mn.
- Suvdantsetseg B, Fukui H, Tsolmon R. 2008. Saxaul forest area determination by remote sensing in Mongolia's Gobi Region. In *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. 1081–1086.
- Tsogtbaatar J. 2004. Deforestation and reforestation needs in Mongolia. *For Ecol Manage*. 201(1):57–63.
- Tsogtbaatar J. 2013. Deforestation and reforestation of degraded forestland in Mongolia." Tokyo: Springer, p. 83–98.
- USDA. 2018. "Forest Operations Equipment Catalog: Cable Logging." 2018. [accessed 2020 Feb 16]. <https://www.fs.fed.us/forestmanagement/equipment-catalog/cable.shtml>.
- Wang Q, Atkinson PM. 2018. Spatio-temporal fusion for daily sentinel-2 images. *Remote Sens Environ*. 204:31–42.
- Wei H, Wang J, Cheng K, Li G, Ochir A, Davaasuren D, Chonokhuu S. 2018. Desertification information extraction based on feature space combinations on the mongolian plateau. *Remote Sensing*. 10(10):1614.